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BUSHLAND WEIGHING LYSIMETER DATA ACQUISITION SYSTEMS FOR EVAPOTRANSPIRATION RESEARCH

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SUMMARY:

Data acquisition systems used to measure the outputs from load cells on large weighing lysimeters and the instrumentation for micrometeorological measurements at each lysimeter site and a weather station at the USDA-ARS Conservation and Production Research Laboratory, Bushland, TX, are described. The procedures for data acquisition, interfacing of instruments, telecommunication, etc. are discussed.

KEYWORDS:
Lysimeter, instrumentation, micrometeorological, data acquisition, data processing and storage

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BUSHLAND WEIGHING LYSIMETER DATA ACQUISITION SYSTEMS FOR EVAPOTRANSPIRATION RESEARCH[1/]

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INTRODUCTION

Weighing lysimeters are commonly used to directly measure the evaporation (E) from soil surfaces and evapotranspiration (ET), which combine processes of evaporation and transpiration (T) from crops or other natural vegetation. Many reviews of lysimeter designs are available (Kohnke et al., 1940; Tanner, 1967; Rosenberg et al., 1968; Soileau and Hauck, 1987). Many types of lysimeters along with several different weighing mechanisms have been used in these designs. Each design and scale has certain limitations as well as improvements which have been made to the field of lysimetry. Major advances have been made in field data acquisition systems for recording and processing data from weighing lysimeters.

The purpose of this paper is to describe the data acquisition system for the USDA-ARS weighing lysimeters at Bushland, TX (Marek et al., 1987). The equipment used to measure the other energy balance parameters at each lysimeter will be described, along with the instruments used to measure the routine weather variables in a nearby weather station. Also, the data acquisition procedures, communication between the field data acquisition systems and a microcomputer, data processing, data protection, and final computer storage are described.

LITERATURE REVIEW

The common mode of data acquisition from many early weighing lysimeters has been manual readings of a dial or a balance beam (Pruitt and Angus, 1960). Several mechanical and electronic devices were used to digitize data from scales as described by Harrold and Dreibelbis (1958) and van Bavel and Myers (1962). These devices are not compatible for direct computer input except by either manual keyboard entry, by digitalization, or by punched paper tape from teletypes. Many weighing lysimeters used strip chart recorders for permanent data records or digital data acquisition systems(Ritchie and Burnett, 1968; Armijo et al., 1972).

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McFarland et al. (1983) described the use of Campbell CR-21[3/] for data acquisition of a load-cell weighing device for a large weighing lysimeter. Howell et al. (1985) described one of the first weighing lysimeters with microcomputer data acquisition systems for both control as well as data acquisition. Dugas et al. (1985) described the use of a Campbell CR-7 for a weighing lysimeter data acquisition system. Howell et al. (1985) described how the data could be transmitted from the lysimeter site to a remote microcomputer for data processing using telecommunications.

The current state of the art for field recording of data from a weighing lysimeter appears to have electronic accuracy of near 0.02% from an analog signal up to ±5 volts, full data precision of 16 bits, immediate field preprocessing, including statistical summaries (means, standard deviations, maximums, minimums, etc.), primary and secondary methods of data storage (random access memories, digital tapes, etc.), and the ability to communicate to remote sites by telephones, satellite links, radio links, etc.

SYSTEM DESCRIPTIONS

Lysimeter and Weather Station Sites

The weighing lysimeters are located at Bushland, TX (35° Lat., 102°W Long., 1,170 m elevation MSL) and were described by Marek et al. (1987). Four weighing lysimeters are located in a 20-ha field with each lysimeter located in the center of a subfield of about 5 ha (210 m by 225 m). The field topography is relatively level with a slope of less than 0.15%. No vertical obstructions are near the field; and over 1,000 m of cropped, unobstructed upwind fetch (in the predominant summer wind direction) are located next to the lysimeter field. The lysimeters and weather station are located about 2 km west of the Research Laboratory headquarters. The field layout and the prevailing land use near the lysimeters are illustrated in Fig. 1.

The weather station is located immediately east of the lysimeter field (Fig. 1). It is 42-m square in size, dead level, planted to a cool season grass mixture, and irrigated by surface flooding. An all-weather field road permits travel to the weather station during inclement weather.

Underground electrical power lines (480-volt service) have been installed to all the weighing lysimeters and the weather station (Fig. 2). The 480-V power is then transformed to 120 V for powering the data systems and other equipment. Irrigation pipelines have been installed to supply pressurized (350 kPa) water to the lysimeter field to operate a 450-m lateral-move irrigation system (Lindsay) and to water supply and irrigation hydrants in the weather station. Underground telephone lines have been installed to the weather station and to the northeast and northwest weighing lysimeters (the main data acquisition systems) (Fig. 2).

3/ Mention of a trade name or product does not constitute a recommendation or endorsement for use by the U.S. Department of Agriculture, nor does it imply registration under FIFRA as amended.

All instrumentation wiring from the surface enters the lysimeter through terminal blocks mounted in weatherproof electrical boxes. Two identical sets of terminal blocks are used, one at the soil surface and another inside the lysimeter, with multistranded cables and a 15-pair thermocouple extension in the conduit between them. This setup facilitates ease of changing instruments or adding new instruments as the needs arise.

LYSIMETER INSTRUMENTATION

Lysimeter Scales

The weighing lysimeters use Cardinal Manufacturing Co. Model FS-7 lever scales with a mechanical advantage of 100:1 at the load cell. The gross mass on the scale is counterbalanced so that about 2,200 kg of active load (primarily the mass of the growing crop and plant available water in the soil) is transferred to the load cell. The load cell is a 22.7 kg strain gage (Alphatron Model SL50lbs-0), which is a precision S-type cell. This load cell can be safely overloaded to 150% of capacity, uses excitation voltages up to 15 V-dc, has a rated precision of 0.06% (nonlinearity, hysteresis, and nonrepeatability), and has a nominal output of 3 mV per V of excitation. The nominal precision of the lysimeter scale and load cell should approach about 0.15 mm of water mass equivalence (1.4 kg).

LYSIMETER MICROMETEOROLOGICAL EQUIPMENT

Many micrometeorological parameters are measured at each lysimeter to determine vertical profiles of wind, air temperature, vapor pressure, energy balance, and radiation balance components. Specific instrumentation details are summarized in Table 1A.

Radiation Measurements

Reflected solar radiation is measured with inverted Eppley black and white pyranometers (Model 8-48); reflected photosynthetically active radiation (PAR) is measured with inverted Li-Cor quantum sensors (Model LI-190SA); and net radiation is measured with Micro-Met miniature net radiometers (with hard domes). All of these measurements are made from the north side of each lysimeter (0.37 m from the edge of the lysimeter) with instrument arms that extend 1.0 m over the edge of the lysimeter from a mast that can be easily raised or lowered to maintain each instrument level at 0.5 to 1 m above the surface.

Transmitted PAR is measured with Li-Cor linear quantum sensors, Model LI-191SA; transmitted solar radiation is measured with Delta-T linear pyranometers (TS-b3); and net radiation is measured with Delta-T linear net radiometers (TRL/M-3). All transmitted radiation parameters are measured just above the soil surface (0.025 m above the top of the beds), and the sensors are located diagonally between two rows for 0.76-m row spacings and perpendicular between the rows for 1.0-m row spacings. The tube net radiometers are continually pressurized with dry air using an aquarium pump operating with 120 V-ac power and desiccant to dry ambient air and minimize condensation inside the domes or tubes.

The surface temperature of the crop and soil is measured with two 15° field-of-view Everest Interscience Model 4000 miniature infrared thermometers (IRT). One IRT is directed diagonally toward the crop at about 60°from vertical (NADIR), and the other is aimed directly NADIR. The IRT's are photo-chopper stabilized and are located on masts that can be moved vertically to maintain the desired view areas of the lysimeters.

Soil Thermal Properties and Heat Flux

The mean soil temperature of the 0- to 100-mm depth is measured with 2 grounded Cu-Co thermocouples (Omega Engineering Model TM*SS125g) wired in parallel and placed at 25 and 75 mm below the soil surface. The thermal conductivity at the 0- to 100-mm soil depth is measured with Delta-T thermal conductivity probes (Model TC-1) inserted horizontally. Soil heat flux at 100 mm depth is measured with Micro-Met thermopile heat flux plates. Four individual soil heat flux plates are located in the center of 2 furrows and on top of 2 beds. The soil thermocouples are located adjacent to these measurement sites. Two soil thermal conductivity probes are located near the center of a bed and the center of a furrow. Two furrows and two beds are measured due to differences in irrigation if alternate row irrigation is practiced (low energy, precision application, LEPA systems). The vertical positioning of the soil thermal sensors is illustrated in Fig. 3.

Horizontal Wind Speed Profile

Horizontal wind speeds are measured 0.2, 0.5, 1.0, and 2.0 m above the crop surface with cup anemometers (Met-One Model 014A). The anemometer masts, located immediately to the southwest (0.5-m) of each lysimeter, can be raised 1.5 m as a unit without moving individual anemometers.

Air Temperature and Vapor Pressure Profiles

Air temperature and vapor pressure profiles are measured with aspirated, radiation shielded psychrometers constructed as shown in Fig. 4. They are similar to the design by Lourence and Pruitt (1969) which use ceramic wet-bulb wicks. The dry- and wet-bulb temperature elevations are the same as the wind speed profiles. The mast for the psychrometers can be raised 1.5 m as a unit without moving individual psychrometers. The psychrometers use Cu-Co thermocouples (Omega Engineering Model TM*SS125u) and are calibrated against a standard Assman psychrometer (Weathermeasure Model H332). The psychrometers are aspirated by 120 V-ac powered squirrel-cage fans (Dayton Model 2C782). The psychrometers are insulated with 6 mm thick foam pipe insulation and covered with a reflective chrome mylar tape. The dry-bulb thermocouple is located sufficiently upwind to minimize heat transfer effects from the wet-bulb wick. Both the dry- and wet-bulb sections of the psychrometers are modularized to facilitate the rapid transfer of other sections as replacements in case of individual thermocouple malfunctions. The psychrometer mast is located just southeast (0.5 m) of each lysimeter.

Rainfall and Sprinkler Irrigation Application Measurements

A tipping-bucket rain gage (Sierra-Misco Model 2500) with a precision of 0.25 mm is located adjacent to each lysimeter. The elevation of the rain gage is maintained near to the top of the crop and about 2 m just east of the lysimeter adjacent to the personnel access door of the lysimeter.

WEATHER STATION EQUIPMENT

The station is equipped for wind speed (2- and 10-m elevations), wind direction, air temperatures (2- and 10-m elevation), shelter height temperature and relative humidity, shelter dew point temperature, barometric pressure, water evaporation from U.S. Weather Bureau Class A pans (open and screened), precipitation, and different incident and diffuse solar radiation parameters (Table 1B).

10-m Mast Measurements

A 10-m vertical mast (Rhome Model 25G) radio tower is used to provide the measurement platforms for 2- and 10-m air temperature (Campbell Scientific Model 107 thermistor), 2- and 10-m horizontal wind speed (Met-One Model 014A), and 10-m wind direction (Met-One Model 024A). The air temperature sensors are mounted in naturally aspirated radiation shields (Sierra-Misco Model 4550).

Instrument Shelter Measurements

A Cotton Belt instrument shelter (Sierra-Misco Model 4525) is used to house a Campbell Scientific Model 207, temperature-relative humidity probe (Pope cell with a thermistor for temperature), a barometric pressure transducer (YSI Model 2014-745/1050mb-3), and a Li-Cl dew cell (YSI Model 9400A) with a platinum resistance temperature probe. The dew cell requires 120 V-ac power for the translator to supply the heating current for the dew cell bobbin.

Evaporation Pans and Precipitation Gages

Two U.S. Weather Bureau Class A pans are located in the weather station. The pans (Sierra-Misco Model 3005) are equipped with water level recorders (Sierra-Misco Model 3003) that are float-driven, continuous-turn 10-kΩ resistors. One of the evaporation pans is covered with an angle-iron frame with a 25-mm mesh wire (chicken wire) covering to limit effects from birds, animals, etc. (Howell et al., 1983). A standard 200-mm U.S. Weather Bureau manual rain gage (Sierra-Misco Model 2510) and a thermostatically-controlled, electrically-heated tipping-bucket rain/snow gage (Sierra-Misco Model 2500E) with 0.25-mm precision is also located in the weather station.

Radiation Measurements

An extensive array of radiation instruments are used to measure incident and diffuse radiation parameters. All radiation instruments are located on an instrument bench located 2.0 m above ground level with each instrument's sensing element at the same elevation. Incident solar radiation is measured with an Eppley Model PSP pyranometer and with a Li-Cor Model LI-200SA silicon cell pyranometer. Incident PAR is measured with a Li-Cor Model LI-190SA quantum sensor, incident PAR irradiance is measured with a Skye Model SKE510 PAR energy sensor, and received long-wave sky radiation is measured with an Eppley Model PIR pyrgeometer. Diffuse solar radiation is measured with an Eppley shadow band. Diffuse PAR and diffuse PAR irradiance are measured with shop-constructed miniature shadow bands based on the Li-Cor Model 2010s (no longer commercially available).

DATA ACQUISITION SYSTEMS

Campbell Scientific CR-7X data acquisition systems are used to measure the analog outputs from the various sensors at each lysimeter and the weather station. A master CR-7X (with a Campbell Scientific Model 720, control module I/O interface) with a DC-103A modem is located in the northeast and northwest weighing lysimeter sites. The other weighing lysimeters have slave CR-7 control units. The master units communicate through hardwired (buried multistrand cables) serial communication to the lysimeter slave dataloggers (Fig. 2). Each lysimeter data system contains separate power supply units which supply the required 12 V-dc to operate the data acquisition systems and analog interface cards. Each datalogger is continually charged through a 120 V-ac power line. Each lysimeter CR-7 unit is composed of: (1) analog card (Campbell Scientific Model 723T) containing an RTD thermocouple reference and 14 differential channels or 28 single-ended channels); (2) analog card without RTD (Campbell Scientific Model 723) containing 14 differential channels or 28 single-ended channels; (3) 2 pulse-counting cards (Campbell Scientific Model 724) containing 4 channels for frequency or contact closure measurement each; and (4) excitation card (Campbell Scientific Model 725) containing 8 channels of switched analog output, 2 channels of continuous analog output, and 8 channels of digital control output (Table 2).

An individual CR-7X datalogger with a Campbell Scientific DC-103 answer modem is used for the weather station. The weather station CR-7X contains an RTD card, an excitation card, and a pulse-counting card.

Each of the master CR-7X units and the weather station CR-7X contain 64k of random access memory (RAM) to store over 14,000 five-digit (plus polarity) datapoints or more than 1.5 days of data from the 2 lysimeters (master and slave controlled) and to store over 5 days of data from the weather station.

The slave-master system configuration is utilized for the lysimeters to minimize initial costs (700X control modules are not necessary for the slave units) and to permit minimal telephone communication with all the units. The master units also use a cassette tape recorder to provide a field backup for data storage. The slave CR-7 systems can be easily converted to individual CR-7X systems by the addition of control modules if necessary.

The CR-7Xs are programmed to record the data in basically the analog form to simplify the programming and to insure minimum program execution time. Calculated execution time of the existing programs in use by the datalogger indicates the CR-7X master units are at about 65% of capacity; thus, the conversion of the analog signals to engineering and scientific units is accomplished by the microcomputer (to be described later).

Telecommunication between the microcomputer and the CR-7Xs is at 300 bits per second (baud rate). The master CR-7Xs communicate to the slave

CR-7s (distance is about 220 m) at 38,400 baud. The CR-7X outputs are summarized in Tables 3 and 4, which list the output parameters and their time sequences for the lysimeters and the weather station systems.

A microcomputer (Compaq Model 286 Deskpro) equipped with a 30-Mb hard disk, 1-Mb internal RAM (random access memory), a Campbell Scientific Model PC-201 card, and external 1200 baud modem (Hayes, Smartmodem 1200) automatically powers up at a preset time (0100 hours), self boots (loads the MS-DOS operating system), and executes the Campbell Scientific PC-205 telecommunications software. The program instructs the modem to dial the weather station telephone number. Upon connection, the computer interrogates the CR-7X, which sends the internally stored data to the microcomputer which stores the data on the hard disk in a predetermined file. On completion of the data dump, the computer terminates the telephone call and then proceeds to follow the same procedure to call the lysimeter CR-7Xs. Then the program powers down the microcomputer and peripheral equipment.

DATA COLLECTION, PROCESSING AND STORAGE

Data Collection

Data collection by the CR-7X systems in the lysimeters are from two programmable tables, with each having a different scan interval. Table 1 of the CR-7X has priority over Table 2. The load cell is scanned every second in Table 1 and integrated for output every 5 min. A CR-7X data dump includes an automatic identifier of the output program number and a program-controlled output of the day of year, hour and minute, year, load-cell integration and standard deviation (Table 3).

The energy balance instrumentation (pyranometer, thermocouples, anemometers, etc.) are scanned every 6 s (0.1 min) and integrated for output every 15 min as the identifier, day, hour and minute, year, and the 32 instruments being scanned. The exception to this is a once-a-day (midnight) reading of the thermal conductivity (TC) probes. The reading of these for the master and slave requires approximately 5 min, during which time all readings except the load cell are suspended. The TC probe readings are a series of temperature readings after an initial excitation (heating) as a measure of heat conductance of the soil. The TC measurements are used to correct the soil heat-flux plate (Phillip, 1961). The soil temperature measurements in the soil surface layer are used to estimate the change in the soil heat storage above the the soil heat-flux plates (Fritschen and Gay, 1979).

Data integration and output from the weather station are similar to the energy balance data from the lysimeter sites. All the instruments are scanned every 6 s (0.1 min) and integrated for output every 15 min. Output includes the identifier, day of year, hour and min, year, and integration of the 22 instruments plus a single sample (one instantaneous reading at the end of the 15-min period) for wind direction and the 2 evaporation pans for a total of 25 channels. At 2400 hours, another output is generated which outputs the identifier, day and year with the maximum and minimum temperature and humidity readings and time for the previous 24-h period.

Data Processing

The data as downloaded (telecommunications or tape read) from the CR-7Xs are in ASCII format. The first step of processing is to combine each day's data with previous data to form 10-day datasets for each lysimeter and the weather station. The use of a word processing program (Wordstar 4.0) in nondocument mode makes this quite simple. Each day of data is visually checked as it is combined for blatant errors such as unusual voltages or missing data indicating an instrument failure. At the end of a 10-day period, computer programs (Quickbasic v. 3.0 and/or Fortran) are used to check for missing time periods, to insert any time not recorded, and to fill the missing period with a missing data identifier (-99.9 in this case). This process insures a uniform number of outputs per day and 10-day dataset. The next step is to break the datasets into individual files of comparable instruments (wind speed, wet bulb, dry bulb, reflected and transmitted solar radiation, etc.). These files are then converted into scientific or engineering units for each of the instruments where applicable and plotted by using a graphics program (Enertronics Energraphics v. 2.1). This graphic presentation provides a visual (CRT) inspection of the data. When a datapoint is determined as unusual or bad, the file can be loaded into the word processor, inspected, and the bad number or numbers replaced with the missing data identifier. This data is then plotted again, with a rough dot-matrix printer hardcopy of the data placed in a binder for future reference.

The data are then processed into 30-min averages for tables of final output. The tables are then released to cooperating scientific team members as either hardcopies, diskettes, or is available by telecommunications through a VAX minicomputer at the Research Laboratory. None of the data prior to this tabularization is released to prevent possible erroneous calculations and, thus, several possible datasets from one lysimeter site.

Data Storage

At each step of data processing, the data is backed up. The original tapes from the CR-7Xs are kept for possible rereading if necessary. The original data as read from the lysimeters and weather station tapes or by telecommunications are archived (PK Ware Archivial Compression, shareware available on most bulletin boards) and stored on backup tapes and diskettes. The third level of backup is after calculations (scientific and engineering units) and plots of the data have been made. These data are again archived and stored on diskette and backup tapes. The final tabularized data is in printed tables, archived for diskette distribution, backed up on tape, and as ASCII files on the VAX system, which is also routinely backed up to tape.

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TABLE 1A. LISTING OF THE INSTRUMENTATION USED AT EACH LYSIMETER, NUMBER OF INSTRUMENTS USED, AND THE TYPE OF DATA OBTAINED.

Manufacturer and model	Instrument description	#/Lysimeter	Measurement
RADIATION INSTRUMENTATION			
Li-Cor 190SB	Linear quantum	1	PAR at ground level (transmitted)
Delta-T TS/b3	Tube solarimeter	1	Solar radiation at ground level (transmitted)
Delta-T TRL/M3	Tube net radiometer	2	Net radiation at ground level (transmitted)
Li-Cor 190SA	Quantum sensor	1	PAR 1 m above surface (reflected)
Eppley B&W 8-48	Pyranometer	1	Solar radiation 1 m above surface (reflected)
Micro-met	Miniature net radiometer	1	Net radiation 1 m above surface
SOIL THERMAL INSTRUMENTATION			
Micro-met	Heat flux plate	4	Soil heat flux at 150 mm
Omega TM*SS125g	Grounded thermocouple probe	8	Soil temperature average at 25 and 75 mm
Delta-T TC-1	Thermal conductivity probe	2	Soil heat conductivity above 100 mm
AIR AND SURFACE TEMPERATURE INSTRUMENTATION			
Omega TM*SS125u	Ungrounded thermocouple probe	8	Air temperature at .2, .5, 1, and 2 m (wet and dry bulb)
Everest Interscience 4000	Infrared thermometer	2	Surface temperature at 2 angles (NADIR and ~60 deg.)
WIND MOVEMENT INSTRUMENTATION			
Met-One 014A	Anemometer	4	Wind speed at .2, .5, 1, and 2 m
PRECIPITATION AND IRRIGATION INSTRUMENTATION			
Sierra Misco 2500	Rain gage	1	Precipitation and sprinkler irrigation amounts

TABLE 1B. LISTING OF THE INSTRUMENTATION USED AT THE WEATHER STATION, NUMBER OF INSTRUMENTS USED, AND THE TYPE OF DATA OBTAINED.

Manufacturer and model	Instrument	#/Location	Measurement
METEOROLOGICAL TOWER			
Met-One 014A	Anemometer	2	2 and 10 m wind speed
Campbell 107	Thermistor	2	2 and 10 m air temperature
Met-One 024A	Wind direction sensor	1	10 m height wind direction
SHELTER			
Campbell 207	Temperature-humidity probe	1	Air temperature and relative humidity
*YSI 2014-745/1050mb-3	Pressure transducer	1	Barometric pressure
*YSI 9400A	Dew cell	1	Dew point temperature
RADIATION STANDS			
Eppley PSP	Pyranometer	2	Incoming and diffused solar radiation
Skye SKE510	PAR energy sensor	2	Incoming and diffused PAR energy
Li-Cor 191SA	Quantum sensor	2	Incoming and diffused PAR
Li-Cor 200SA	Pyranometer	1	Incoming solar radiation
Eppley PIR	Pyrgeometer	1	Long wave radiation
PRECIPITATION AND EVAPORATION			
Sierra Misco 2510	Rain gage	1	Standard 20 cm manual rain gage
Sierra Misco 2500E	Rain gage	1	Tipping bucket rain and snow gage with thermostat controlled heating element
Sierra Misco 3005	Evaporation pan	2	Standard Weather Bureau Class A pans - screened and unscreened
Sierra Misco 3003	Water level recorder	2	Float driven continuous turn 10,000 ohm resister

*Yellow Springs Instruments

TABLE 2. THE CR-7X MEMORY SPECIFICATIONS AND INPUT CARDS USED AT THE USDA-ARS LYSIMETER FACILITY. (FROM CR-7X MEASUREMENT AND CONTROL SYSTEM INSTRUCTION MANUAL)

Standard CR-7X memory allocation: 24K ROM, 40K RAM, plus 24K Internal memory card (add on)

Available Storage Locations (Programmer controlled)	Input Storage	Int. Storage	Final Storage
	512	1024	28288

723T and 723 ANALOG INPUT CARD (one/lysimeter)

Voltage measurement types	14 differential	28 single ended
Voltage measurement accuracy	0.02% of full scale range (0-40° C)	
Voltage range/resolution	±5V @ 166μV	±1.5 V/50μV
(differential measurement)	±5mV@ 166nV	±1.5mV/50nV
Maximum sample rates	Fast single ended	@ 2.6 ms/channel
	Fast differential	@ 4.4 ms/channel

724 PULSE COUNTER CARD (two/lysimeter)

Pulse counters /card	4
Maximum counts /interval (15 min)	32767 (with overrange detection)
Switch closure	Min switch closed time of 1 ms
	Min switch open time of 4 ms
	Max bounce time of 1.4 ms open not counted

725 EXCITATION CARD (one/lysimeter)

Analog outputs	8 switched 2 continuous
Output voltage	±5 V programmable
Resolution	166 V
Output accuracy	0.02% of full scale range
Maximum output current	25mA @ ±5V, 50 mA @ ±2V
Digital controlled output ports	8

TABLE 3. EXAMPLE OF THREE 5 MINUTE SCANS OF LOAD A CELL AND ONE 15 MINUTE SCAN OF ENERGY BALANCE DATA FROM ONE LYSIMETER ON SEPTEMBER 15, 1987. (THERMAL CONDUCTIVITY PROBE DATA NOT SHOWN.)

01+0103.	02+0257.	03+1235.	04+0087.	05+2.2844	06+.00602		
01+0103.	02+0257.	03+1240.	04+0087.	05+2.2847	06+.00588		
01+0103.	02+0257.	03+1245.	04+0087.	05+2.2846	06+.00622		
01+0210.	02+0257.	03+1245.	04+0087.	05+19.886	06+14.253	07+20.064	08+16.445
09+20.029	10+16.533	11+20.089	12+16.700	13+20.134	14+16.748	15+18.876	16+19.001
17+21.755	18+17.053	19+.04051	20+.43957	21+.80449	22+1.0354	23+.83935	24+.86209
25+.68696	26-.00502	27-.00413	28-.04341	29-.03831	30+20.095	31+20.501	32+3431.0
33+2834.0	34+2447.0	35+2028.0	36+0.0000				

01+0103.	identifier automatically output by CR-7X
02+0257.	day of year
03+1245.	time of day
04+0087.	year
05+2.2846	load cell mV output
06+.00622	standard deviation of load cell (1 s scans for 5 min period)

01+0210.	identifier
02+0257.	day of year
03+1245.	time of day
04+0087.	year
05+19.886	internal temperature of CR-7X
06+14.253	battery voltage (charging circuit operating)
07+20.064	dry bulb temperature at 2 m
08+16.445	wet bulb temperature at 2 m
09+20.029	dry bulb temperature at 1 m
10+16.533	wet bulb temperature at 1 m
11+20.089	dry bulb temperature at 0.5 m
12+16.700	wet bulb temperature at 0.5 m
13+20.134	dry bulb temperature at 0.2 m
14+16.748	wet bulb temperature at 0.2 m
15+18.876	soil temperature (furrow)
16+19.001	soil temperature (bed)
17+21.755	soil temperature (furrow)
18+17.053	soil temperature (bed)
19+.04051	Li-cor quantum sensor mV output (reflected)
20+.43957	Eppley pyranometer mV output (reflected)
21+.80449	Micro-Met miniature net radiometer mV output
22+1.0354	Li-Cor linear quantum mV output (transmitted)
23+.83935	Delta-T tube solarimeter mV output (transmitted)
24+.86209	Delta-T tube net radiometer mV output (transmitted)
25+.68696	Delta-T tube net radiometer mV output (transmitted)
26-.00502	heat flux plate mV output
27-.00413	heat flux plate mV output
28-.04341	heat flux plate mV output
29-.03831	heat flux plate mV output
30+20.095	Everest Interscience IRT
31+20.501	Everest Interscience IRT
32+3431.0	wind pulse at 2 m
33+2834.0	wind pulse at 1 m
34+2447.0	wind pulse at 0.5 m
35+2028.0	wind pulse at 0.2 m
36+0.0000	rain gage pulse

TABLE 4. SAMPLE OUTPUT OF CR-7X FOR THE USDA-ARS WEATHER STATION AT 11:30 AM ON NOVEMBER 13, 1987.

01+0115.	02+0317.	03+1130.	04+0087.	05+14.256	06-246.05	07+6.5044	08+6.3928
09+6.5440	10+3.3089	11+1.5415	12+.66322	13+.44244	14+.32316	15-2.4984	16+13.729
17+14.241	18+154.60	19+215.19	20+325.73	21+15.508	22+27.364	23+86.890	24+3397.0
25+2993.0	26+0.0000	27+154.62	28+215.22	29+298.79	30+26.040		

01+0115	identifier automatically output by CR-7X system
02+0317.	day of year
03+1130.	time of day
04+0087.	year
05+14.256	battery voltage
06+14.998	CR-7X internal temperature (RTD)
07+6.5044	Eppley mV output
08+6.3928	Li-Cor pyranometer
09+6.5440	Li-Cor quantum sensor
10+3.3089	Skye PAR energy sensor
11+1.5415	Eppley pyrgeometer
12+.66322	Eppley pyranometer (diffused)
13+.44244	Li-Cor quantum (diffused)
14+.32316	Skye PAR energy (diffused)
15-2.4984	dew point
16+13.729	10 m temperature
17+14.241	2 m temperature
18+154.60	integrated unscreened evaporation pan
19+215.19	integrated screened evaporation pan
20+325.73	integrated wind direction (degrees)
21+15.508	shelter temperature
22+27.394	shelter humidity
23+86.890	barometric pressure (mb)
24+3397.0	10 m pulse count
25+2993.0	2 m pulse count
26+0.0000	precipitation pulse counts
27+154.62	sample of unscreened evaporation pan
28+215.22	sample of screened evaporation pan
29+298.79	sample of wind direction
30+26.040	sample of shelter humidity

Sample output of CR-7X weather station output at 2400 hours on November 13, 1987 for maximum and minimum temperature and humidity and time of the occurrence.

01+0122.	02+0319.	03+0000.	04+0087.	05+19.864	06+1438.	07+73.858	08+0350.
09+2.6630	10+0345.	11+16.292	12+1413.				

01+0122.	identifier number
02+0319.	day of year
03+0000.	time of day
04+0087.	year
05+19.864	maximum temperature
06+1438.	time of maximum temperature
07+73.858	maximum humidity reading
08+0350.	time of maximum humidity reading
09+2.6630	minimum temperature
10+0345.	time of minimum temperature
11+16.292	minimum humidity reading
12+1413.	time of minimum humidity reading

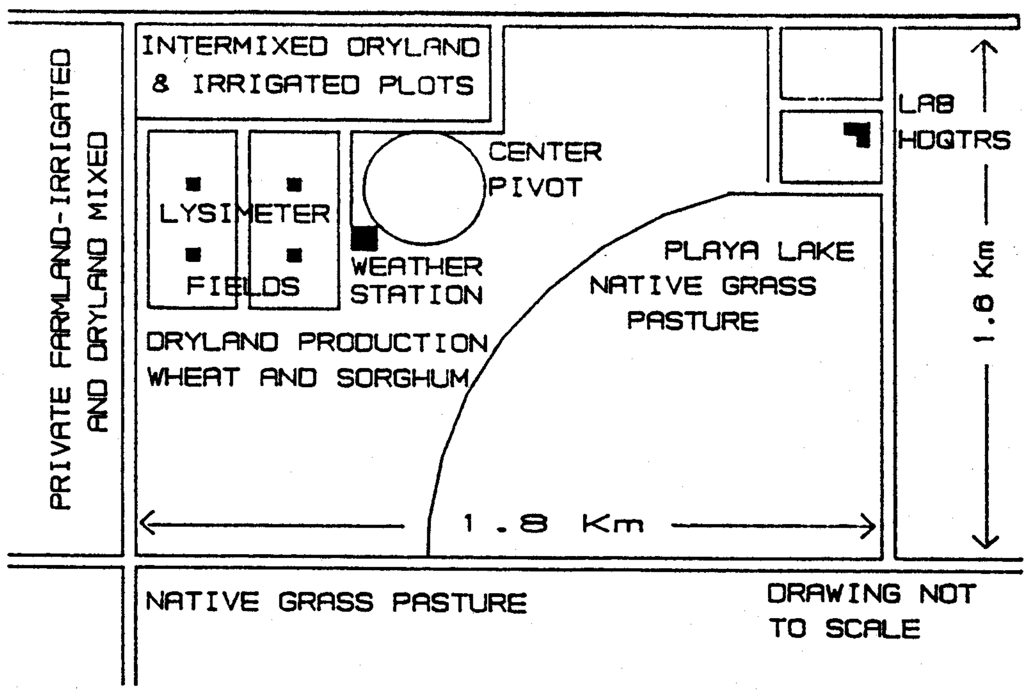

Fig. 1. Lysimeter sites including the weather station and the surrounding fetch at the USDA-ARS Research and Production Laboratory, Bushland, TX.

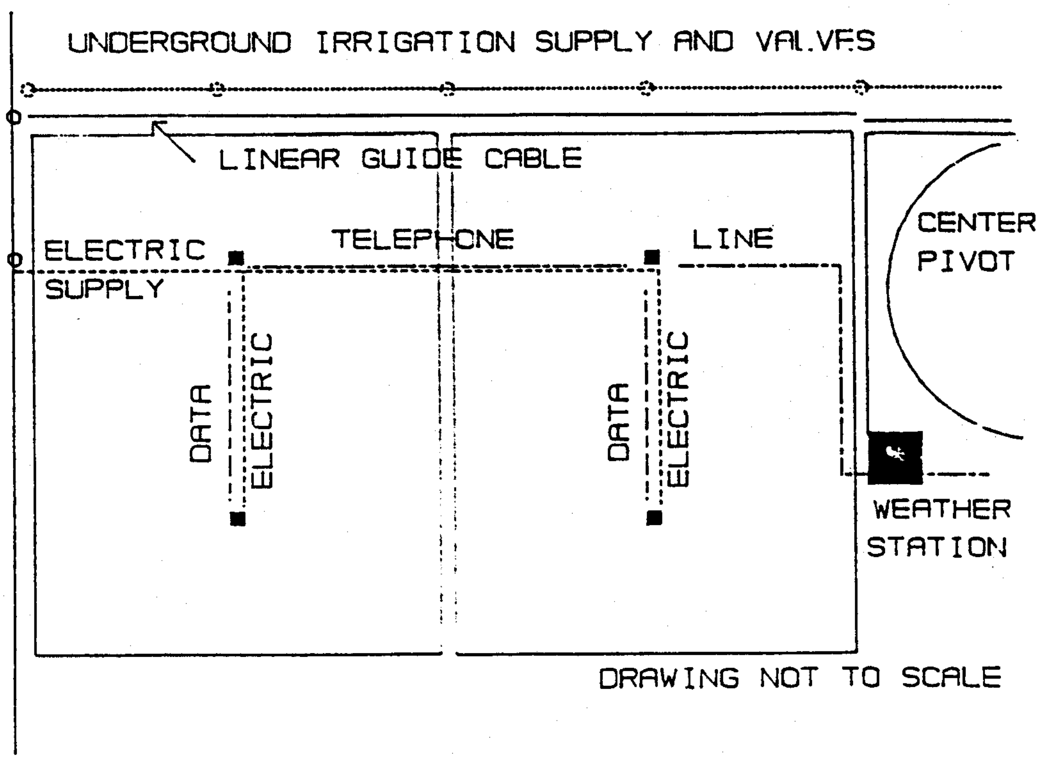

Fig. 2. Detail of the lysimeter fields showing the paths of electrical, telephone, and data lines, and water distribution system.

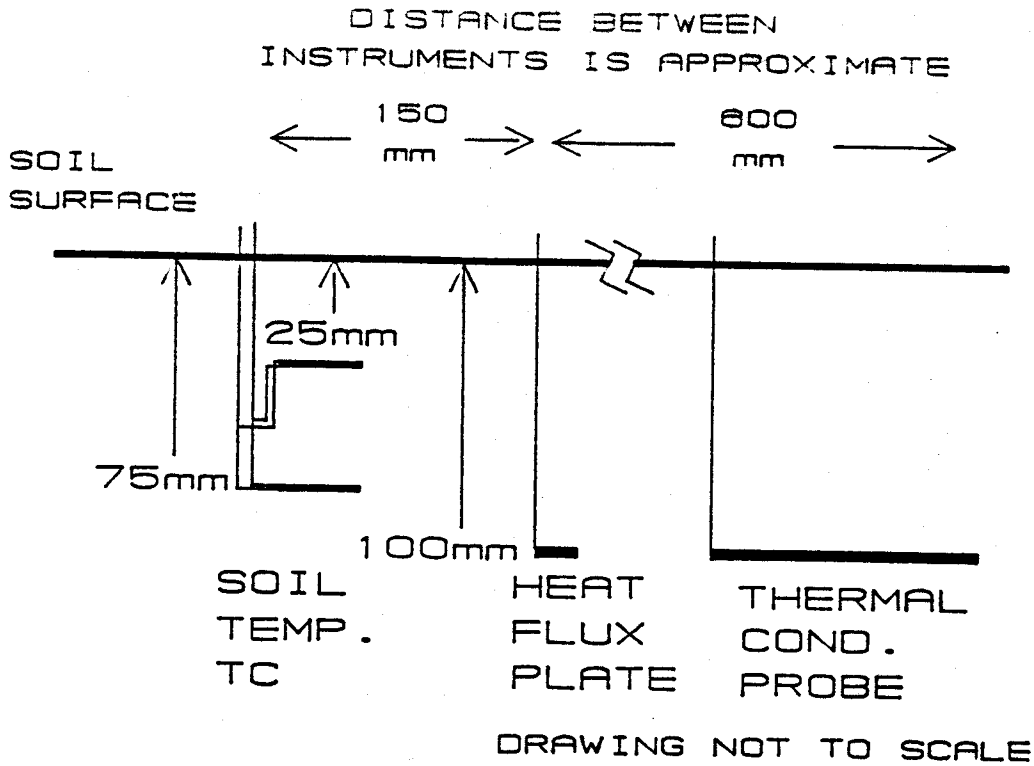

Fig. 3. Representation of the soil thermal instrumentation depths for each lysimeter.

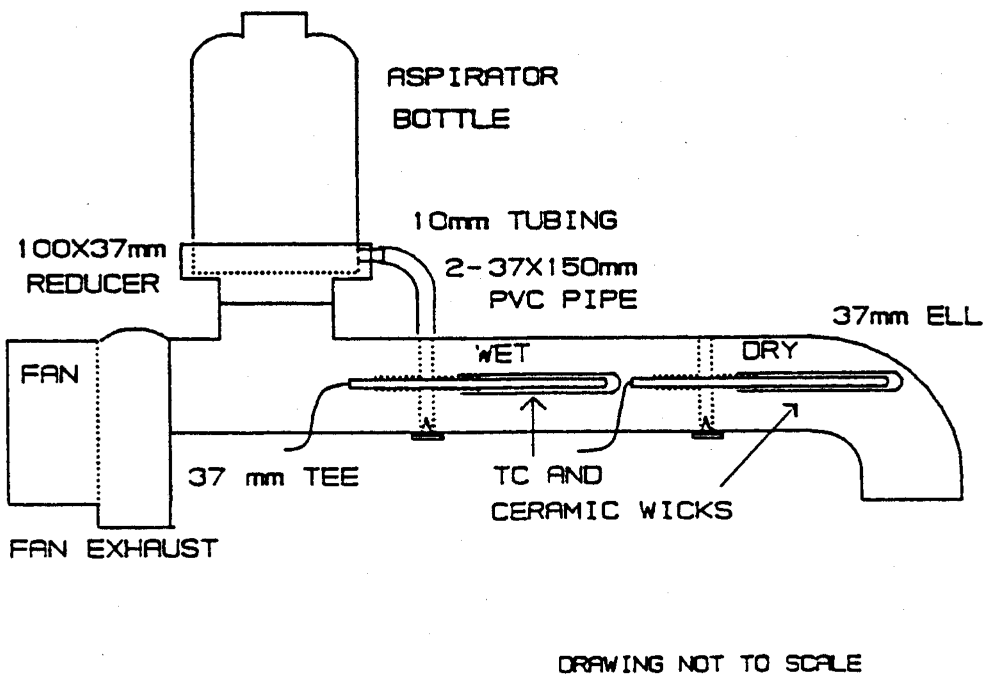

Fig. 4. Descriptive internal drawing of the wet- and dry-bulb psychrometers used to determine the vapor pressure profiles at each lysimeter site.

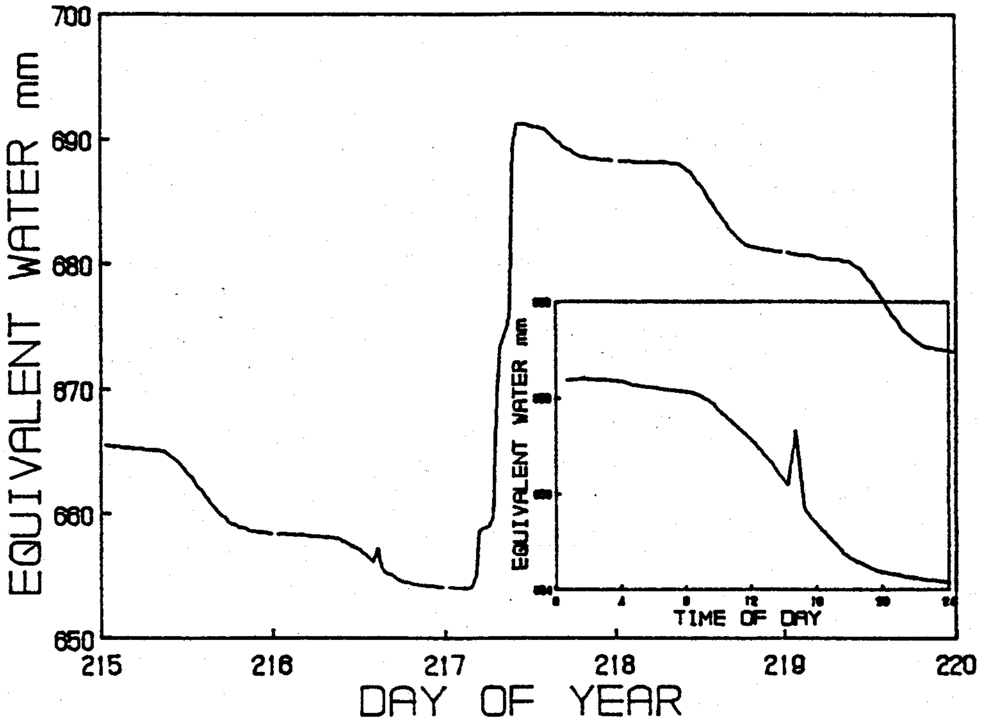

Fig. 5. A graph of a lysimeter load cell showing evapotranspiration and some datapoints (day 216 insert) where someone was on the lysimeter to check and clean radiation instrumentation before an irrigation.